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RECEPTION OF FREQUENCY MODULATED WAVES AND CIRCUITS THEREFOR

Filed Jan. 23, 1936

2 Sheets-Sheet 1

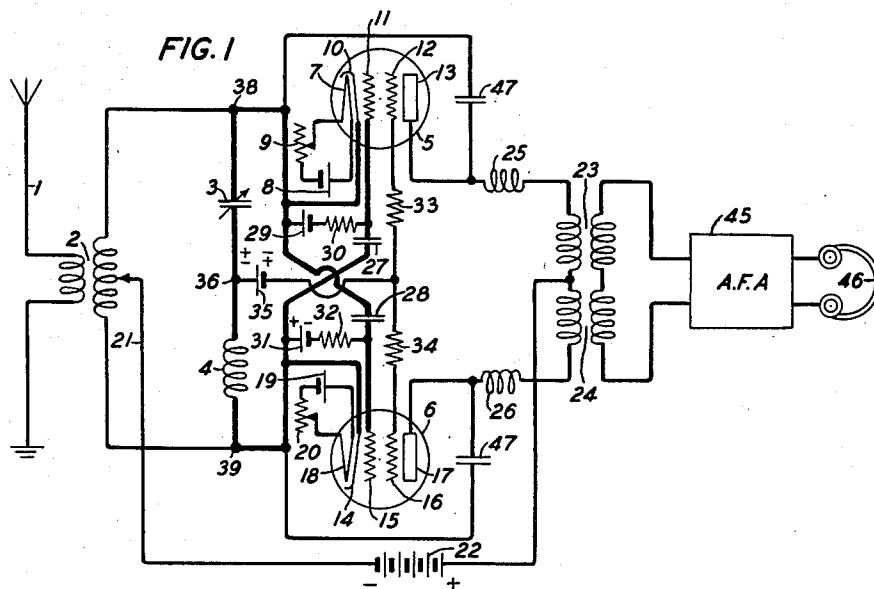


FIG. 2

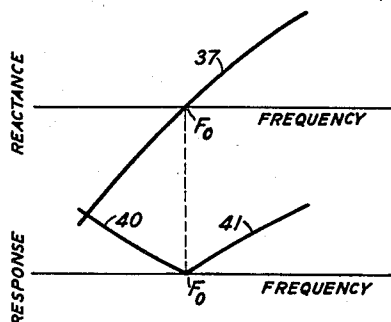
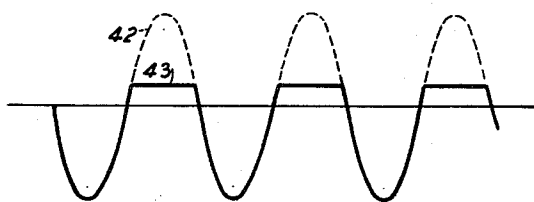


FIG. 3



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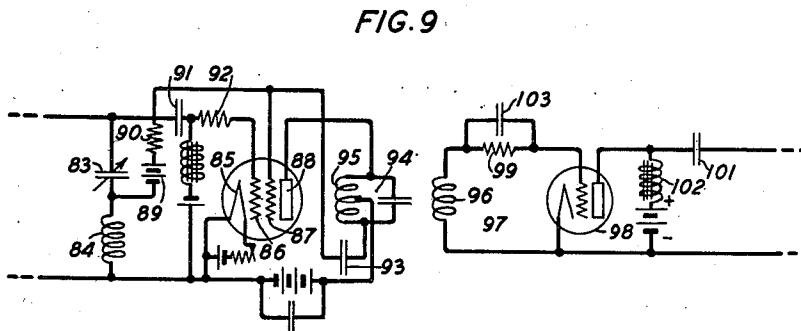
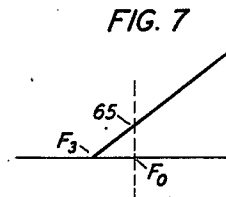
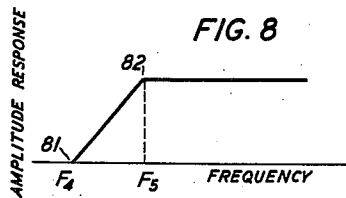
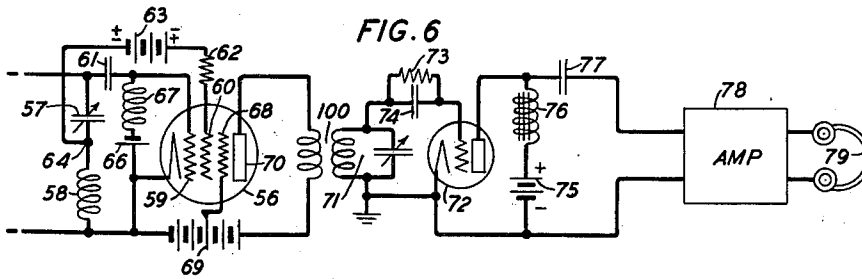
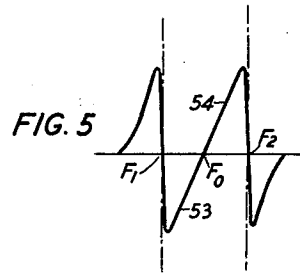
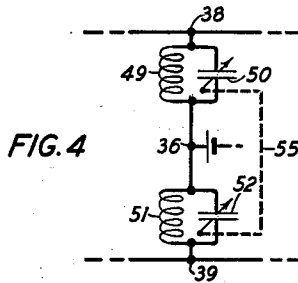
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RECEPTION OF FREQUENCY MODULATED WAVES AND CIRCUITS THEREFOR

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2 Sheets-Sheet 2



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RECEPTION OF FREQUENCY MODULATED WAVES AND CIRCUITS THEREFOR

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Application January 23, 1936, Serial No. 60,420

10 Claims. (Cl. 250-20)

This invention relates to electron discharge systems for selectively responding to oscillations with a definite frequency limit. More particularly, it relates to amplifiers of the type used for converting frequency modulated waves to amplitude modulated waves and to detecting systems for detecting frequency modulated waves.

In reception of frequency modulated waves it is customary to use a conversion unit to convert frequency modulations to amplitude modulations. This unit ordinarily takes some form of tuned circuit. An object of the present invention is to provide a conversion and detection device which, in addition to its function of converting from frequency modulated waves to amplitude modulated waves, possesses such characteristics that it will not respond to oscillations above a fixed frequency or below a fixed frequency as may be desired in the particular case.

In detecting frequency modulated waves, it is desirable to use a balanced detector in which during non-signaling intervals any response to the unmodulated carrier wave is balanced out. This tends to eliminate both tube noise and static hiss which would otherwise be transmitted by the circuits as modulations imposed by the receiver upon the incoming carrier wave. An object of the invention is to provide a detecting system which shall be unresponsive to carrier waves of the normal or unmodulated frequency.

It is customary, in detection of frequency modulated waves, to convert the frequency modulations to amplitude modulations by impressing the frequency modulated waves upon a tuned circuit which yields varying amplitudes in response to different frequency electromotive forces according to whether the frequency approaches or recedes from the resonance frequency of the circuit. The sides of the resonance curve of the usual tuned circuit are not linear and particularly toward the lower portions the curvature introduces a non-linearity which gives rise to distortion in the resulting amplitude modulations. A further object of the invention is to provide a selective circuit for frequency to amplitude conversion systems which will have a more nearly straight response characteristic than that of the usual tuned circuit.

An additional object of the invention is to provide an easily adjustable circuit by which movement of a single element may control the relation of the resonant frequency of the conversion circuit to the carrier frequency for two detectors simultaneously.

In accordance with the invention, incoming frequency modulated waves are impressed upon a

tuned path comprising an inductance element and a capacity element which may be connected in series. The tuned path is resonant or has zero series reactance at the normal or unmodulated carrier frequency of the incoming wave. An electron discharge detector having a cathode connected to the outer end of the inductance element and a control grid connected to the outer end of the capacity element is effectively connected across an inductance at frequencies above normal and across a capacity at frequencies below normal. The detector has an additional grid connected to the junction point of the inductance element and capacity element, and hence, always subject to the electromotive force impressed by the inductance element alone. It follows that for frequencies above normal both grids are subject to inductance electromotive forces and thus being in phase, permit current to pass through the discharge device. At input frequencies below normal, the grids are of opposite phase and current through the discharge device is blocked. Accordingly, the device responds only to frequencies above normal. Its response is made proportional to the deviation from normal frequency.

In order to secure the desired balance at normal frequency, a second electron discharge detector similar to the first is also connected to the series tuned path but in opposite fashion, that is, so that its cathode is connected to the other terminal of the capacity element. For frequencies below normal, both grids of the second detector will be subjected to potentials which are in phase and the detector will respond. Outputs of the two detectors are connected in push-pull relation so that response occurs from one tube as the frequency rises above normal and from the other when it falls below normal and any tendency to response at the normal frequency which might introduce tube noise or static during non-signaling intervals is balanced out.

In the drawings:

Fig. 1 illustrates a radio receiving circuit for receiving frequency modulated waves;

Figs. 2 and 3 show graphs to assist in explaining the operation of the receiving circuit of Fig. 1;

Fig. 4 illustrates a modification of a portion of the circuit of Fig. 1;

Fig. 5 is a graph to explain the operation of the circuit of Fig. 4;

Fig. 6 shows a modified circuit of a device for converting from frequency modulated waves to amplified waves with which a separate amplitude modulator detector is used;

Fig. 7 is a graph to aid in explaining the operation of the circuit of Fig. 6;

Fig. 8 is a graph of a device having a frequency amplitude conversion effect over a limited range of frequencies; and

Fig. 9 discloses a combined frequency selective and current limiting device having an operating characteristic of the type indicated by the graph of Fig. 8.

Referring to Fig. 1, a radio receiver circuit is shown comprising broadly tuned antenna 1 and transformer 2 across the secondary winding of which is connected a path comprising variable capacity element 3 and inductance 4 which are together tuned to substantially the normal unmodulated carrier frequency of a frequency modulated wave which it is desired to receive. An electric discharge device 5 of the four-element type comprises the cathode heater 7 having a heating current source 8 and regulating device 9, cathode 10, amplitude control grid 11, phase control grid 12 and anode 13. A similar electron discharge device 6 comprises the cathode 14, amplitude control grid 15, phase control grid 16 and anode 17. A heater 18 in circuit with an external source 19 of heating current and regulating device 20 serves to maintain cathode 14 at a suitable operating temperature. A space current path for device 5 may be traced from cathode 10 through the secondary winding of transformer 2 to lead 21, space current source 22, primary winding of audio-frequency transformer 23 and radio frequency choke coil 25 to anode 13. Similarly, the space current path for device 6 extends from cathode 14, secondary of transformer 2, lead 21, space current source 22, primary winding of audio-frequency transformer 24, radio frequency choke coil 26 to anode 17. The amplitude control input terminals of device 5 are connected to the opposite terminals of tuned path 3, 4, cathode 10 being connected to capacity element 3 and amplitude control grid 11 being connected to the inductance element 4 by way of large capacity stopping condenser element 27. The amplitude control input terminals of device 6 are connected across the same tuned path 3, 4, but in reverse fashion, the cathode 14 being connected directly to inductance 4 and amplitude control grid 15 being connected through stopping capacity element 28 to the outer terminal of capacity element 3. Between cathode 10 and amplitude control grid 11 is a grid bias path including biasing source 29 and high resistance element 30. A corresponding biasing path including source 31 and high resistance element 32 connects cathode 14 to its associated amplitude control grid 15. Phase control grids 12 and 16 are connected through high resistances 33 and 34, respectively, to a terminal of a grid bias source 35, the other terminal of which is connected to the junction point 36 in the tuned path 3, 4.

In accordance with the well-known method of frequency modulation, during one-half cycle of the modulating or signal frequency wave by which the carrier wave is modulated at the transmitting station, the carrier wave increases its frequency by an amount proportional at each instant throughout that half cycle to the instantaneous amplitude of the signal wave thus rising from normal carrier frequency at the beginning of a half cycle to a frequency maximum at the point of maximum signal intensity in the half cycle and then falling until it attains the normal frequency at the beginning of the next

half cycle. During the next half cycle the carrier wave will decrease in frequency from the normal frequency and will attain a minimum frequency at the peak of that signal half cycle returning again to normal carrier frequency as the signal wave returns to its zero intensity magnitude.

It will, therefore, be seen that throughout the modulation process the frequency of the frequency modulated carrier wave will exceed normal frequency during one-half cycle of the signal or modulating wave and will be less than the normal carrier frequency during the reverse half cycle of the signaling wave. At the instant of transition from one-half cycle of the signal wave to the succeeding half cycle and at all times in the absence of modulating signals, the carrier wave will have its normal frequency.

The graph 37 in the upper portion of Fig. 2 illustrates the variation of reactance between the points 38 and 39 with varying carrier frequency. At the normal carrier frequency point F_0 the reactance between points 38 and 39 is zero. As the frequency increases above F_0 the reactance of the path 3, 4 increases in a positive direction as illustrated. As the carrier frequency decreases from F_0 the reactance increases but is of negative sign. Graphs 40 and 41 in the lower portion of Fig. 2 indicate that the effective response voltage or difference of potential developed between points 38 and 39 is zero at the normal carrier frequency F_0 , but increases as the carrier frequency departs from its normal magnitude of F_0 in either direction. Both response characteristics 40 and 41 are indicated as positive for a reason which will presently be explained.

The normal grid bias potentials applied to grids 11, 12, 15 and 16 are so proportioned with respect to the anode potentials impressed on anodes 13 and 17 that in the absence of incoming waves no current flows. The potential on either phase control grid 12 or grid 16 may be represented by a graph, such as is shown in Fig. 3 in which, as indicated in full lines, the potential falls in the negative direction in accordance with the alternating electromotive force applied between the phase control grid and its respective cathode. However, when the applied electromotive force reverses in sign during the succeeding half cycle, as indicated by the dotted curve 42, there is a tendency for the phase control grid 12 to be driven positive with respect to its cathode. Accordingly, a grid leak current will traverse its circuit and a considerable portion of the driving electromotive force will be expended in the high series resistance element 33 so that the resulting potential on the grid 12 will be as indicated at 43. In other words, during its negative half cycle the phase control grid becomes highly negative, thus strongly tending to prevent any electron flow from the cathode to the anode, but during the positive half cycle the phase control grid becomes slightly positive so that it no longer opposes the passage of current from the cathode to the anode. It will be apparent that the electromotive force available for the amplitude control grids 11 and 15 is at all times less than that available for the phase control grids 12 and 16 since the two potential differences between point 36 and points 38 or 39 are each developed across a reactance of one sign, while that developed between points 38 and 39 is the difference of the two potential differences. Preferably, also, the μ or voltage

amplifying factor assignable to grids 12 and 16 should not be less than about one-third of the μ of grids 11 and 15, and may range to a larger magnitude. Under all circumstances where the amplitude control grids and the phase control grids are of opposite phase, the various magnitudes and constants involved are such that the phase control grids prevail and determine the resultant. At all times when the phase control grid 12 is driven negative, no current will flow through the space discharge device for the reason that with the full negative potential impressed on the grid 12, there is too great opposition to electron flow to be overcome by any potential which will be brought to bear upon the grid 11. Accordingly, current will flow through the electric discharge device 5 only when both grids 11 and 12 are simultaneously driven positive by the impressed electromotive force. It will be readily apparent that the input circuit between cathode 10 and phase control grid 12 is connected directly across capacity element 3. If, therefore, the potential on amplitude control grid 11 is to be of the same phase as that upon phase control grid 12, it can only be under such circumstances that the input path 3, 4 across which grid 11 and cathode 10 are connected is capacitive as is the input path 3 of the phase control grid 12. As indicated by the graph 37 of Fig. 2, the input path 3, 4 presents a capacitive reactance only for frequencies lower than the normal carrier frequency F_0 . It follows, therefore, that grids 11 and 12 will be of like phase during the interval that the incoming carrier frequency is less than F_0 , or, in other words, during one-half wave of the modulating signal at the transmitting station. During that interval, electrons will flow from cathode 10 to anode 13 and the resulting impulse of current will have a magnitude determined primarily by the potential of amplitude control grid 11. As indicated by graph 40 of Fig. 2, the positive potential on amplitude control grid 11 is a function of the departure of the carrier wave frequency from its normal frequency and increases as the carrier wave decreases in frequency. Accordingly, the discharge device 5 will transmit to the primary winding of audio-frequency transformer 23 a pulse of current of a duration corresponding to that of a half wave of the modulating or signal wave at the transmitting station and of an intensity proportional at each instant to the difference between the received carrier wave frequency and the normal frequency F_0 . Since that frequency difference is a function of the amplitude of the modulating signal, the resultant impulse supplied to the primary winding of transformer 23 will correspond in amplitude to a half cycle impulse of the modulating wave at the transmitting station.

The operation of discharge device 6 is similar in character to that of discharge device 5. In other words, electrons will not pass from cathode 14 to cathode 17 in the absence of received carrier waves. Moreover, electrons will only pass during that interval in which grids 15 and 16 are in phase and are positive. Since the input circuit of phase control grid 16 is connected across inductance 4, it will be apparent that amplitude control grid 15 will be of like phase with grid 16 only when amplitude control 15 and its cathode 14 are likewise connected across an inductance, or, in other words, when the path 3, 4 is inductive. This condition occurs only when the incoming carrier waves are higher than the nor-

mal frequency F_0 . Without further explanation, it should be apparent that device 5 serves to detect and transmit to the primary winding of its transformer 23 as a half cycle impulse the received carrier waves which are of lower frequency than the normal frequency F_0 . At the time that the incoming carrier wave reaches the normal carrier frequency, the response of discharge device 5 ceases. During the ensuing period when the incoming carrier waves are of frequency greater than F_0 , device 6 delivers to the primary winding of its audio-frequency transformer 24 an impulse constituting the reverse half wave of that previously delivered to the primary winding of transformer 23. From the standpoint of the modulating waves at the transmitting station, discharge device 5 may be considered as transmitting one-half wave and discharge device 6 the reverse half wave. From the standpoint of received carrier waves at the receiving station, device 5 may be considered as demodulating those waves of lower than the normal carrier frequency F_0 and device 6 as demodulating those of higher than the carrier frequency F_0 . Devices 5 and 6, accordingly, operate alternately to supply the opposite half waves of the demodulated signals. Inasmuch as the primary windings of transformers 23 and 24 are differentially connected to the input circuit of audio-frequency amplifier 45, the impulses which they supply thereto will be additive in the proper sense so that amplifier 45 will supply amplified detected signals to the receiving or loud-speaking device 46. By-pass condenser elements 47 permit radio frequency components of the output current to readily pass from each cathode to its respective anode and thereby increase the detecting efficiency of the electron discharge devices. Series choke coils 25 and 26 exclude the radio frequency current from the primary windings of transformers 23 and 24. Inasmuch as neither electron discharge device 5 nor 6 responds at the normal carrier frequency F_0 , the circuit will have the advantage of the balanced frequency conversion circuit. It also permits tuning for any desired normal carrier frequency by variation of the single variable element. Another important feature is that the response characteristics 40 and 41 of the two electron discharge devices are more nearly linear with respect to frequency than are those of devices working with the usual high frequency tuned circuit. The output circuit of the two tubes may be simplified by constructing transformers 23 and 24 as a single transformer with two primary windings and a single secondary winding.

The polarity and magnitude of the grid bias source 35 which polarizes phase control grids 12 and 16 may best be found for the particular tubes employed by experimental determination but, in general, the bias potential will be in the neighborhood of zero or a few volts positive or negative and more generally positive. A negative potential is, however, conducive to saving of power in the grid circuit and may also be desirable where very high plate potentials are employed.

Where it is not desired to use a low impedance input circuit, such as the path 3, 4, there may be connected between points 38 and 39 the circuit illustrated in Fig. 4 in which the tuned loop comprising inductance 49 and variable capacity element 50 may be tuned to frequency F_1 as indicated in Fig. 5 and the tuned loop comprising inductance 51 and variable capacity element 52

may be tuned to the frequency F_2 , as shown in Fig. 5. If the tunings of these two circuits are so chosen that the normal incoming carrier frequency F_0 falls substantially midway between, the device may operate over the range indicated by the portions 53 and 54 of the graph of Fig. 5 in substantially the same manner as the circuit of Fig. 1. With this apparatus, the capacity varying elements of devices 50 and 52 are preferably connected mechanically as indicated at 55 to permit a single adjusting operation to tune the circuit.

Fig. 6 illustrates a circuit in which a single electron discharge device 56 is used to effect conversion of a frequency modulated carrier wave to an amplitude modulated carrier wave and at the same time to amplify the converted wave. For that purpose the input path comprising variable condenser 57 and inductance 58 is tuned to a frequency F_3 as indicated in Fig. 7. With the amplitude control grid 59 connected through a large stopping condenser 61 across the tuned input path and with the phase control grid 60 connected through high resistance 62 and grid bias source 63 to the junction point 64, it will be obvious that the discharge device 56 will have an operating characteristic somewhat resembling that of the device 6 of the circuit of Fig. 1 and will accordingly respond to carrier wave frequencies exceeding the cut-off frequency F_3 as indicated by the substantially linear graph 65 of Fig. 7. The output current of the device 56 will accordingly be of the same frequency as the input current, but will vary in amplitude with increasing carrier frequency of the input electromotive force, the amplitude being substantially proportional to difference between the incoming frequency and the cut-off frequency F_3 . It should be noted that the amplitude control grid 59 is biased to the desired potential by a source 66 in series with choke coil 67.

Included in the device 56 is a shield grid 68 connected to the space current source 69 in the usual manner and serving to prevent electrostatic reaction from the anode 70 of the output circuit from affecting the input electrodes 59 and 60. The output circuit of the device 56 is connected by a radio frequency transformer 100 to the input circuit 71 of an amplitude modulation detecting device 72 of the thermionic type having a grid leak resistance element 73 shunted by the usual grid leak condenser 74. The output circuit of detector 72 comprises a space current path including source 75 and audio-frequency choke coil 76 and an alternating current path by way of stopping condenser 77 to the input circuit of audio-frequency amplifier 78 in the output circuit of which signal indicating device or loudspeaker 79 is connected.

In some instances, it may be desired in reception of high frequency waves to provide an apparatus having a frequency amplitude conversion effect accompanied with an amplitude limiting action, according to the characteristic of Fig. 8, in which the amplitude response begins at a frequency F_4 corresponding to point 81 on the graph and increases linearly with frequency to the frequency F_5 corresponding to point 81 on the graph and is thereafter limited to a substantially constant magnitude. Such a characteristic, it will be observed, differs from the characteristic 65 of Fig. 7 principally in that it has a limited amplitude portion. It is accordingly possible to utilize an apparatus similar to device 56 of Fig. 6, if means be provided to limit the magnitude of the

current passed thereby. As indicated in the schematic diagram of Fig. 9, the apparatus comprises an input circuit having variable tuning condenser 82, inductance coil 84, cathode 85, amplitude control grid 86, phase control grid 87 and anode 88. The phase control grid 87 is connected to the junction point in the tuned input path through a biasing source 89 and a grid leak resistance 90. The amplitude control grid 86 is connected to the outer terminal of condenser 82 through a stopping condenser 91 and a large resistance 92. To neutralize the effect of inter-electrode capacity between anode 88 and phase control grid 87, a neutralizing path including capacity element 93 of well-known type is connected between the output circuit and the grid 87. Amplitude control grid 86 is biased in the same manner as amplitude control grid 59 of Fig. 6. In operation, the device serves to amplify as does the apparatus 56 of Fig. 6. However, when the amplitude control grid 86 is driven sufficiently positive as occurs during the positive cycle of high intensity oscillations, the drop in potential through series resistance 92 is sufficient to limit the effective potential on grid 86. Inasmuch as the discharge device only passes current during the interval in which the grid 86 is positive, it follows that the maximum amplitude of the amplified oscillations transmitted to the output circuit is effectively limited to a magnitude corresponding to that of the point 82 in the graph of Fig. 8. The output circuit 94 is coupled by an inductance 95 serving as a primary winding to a secondary winding 96 in the circuit 97.

The amplifier 56 of Fig. 6 or the amplifier of Fig. 9 may be connected to the input of a straight line detector where high quality is desired. As shown in Fig. 9, the straight line detector may comprise an electron discharge device 98 having a series grid resistance 99 with a shunting condenser 103 in its input circuit. The secondary winding is so designed that the alternating electromotive forces applied to the input circuit of device 98 are of such magnitude as to fall within a range for which the rectified grid current potential is proportional to the input wave envelope. Consequently, there will occur at the grid demodulated or audio-frequency potentials which faithfully represent the modulations of the incoming carrier wave. The output circuit of device 98 is by way of a very large stopping condenser 101. The space current path includes an audio-frequency choke coil 102 which insures that the demodulated current potentials appearing on the grid are repeated without distortion to the output circuit of the device 98.

What is claimed is:

1. An amplifier for amplifying oscillations of frequency above a fixed cut-off frequency without amplifying oscillations below the cut-off frequency comprising an electron discharge device having a cathode, an anode and two interposed grids, an inductance element and a capacity element constituting a series path tuned to the cut-off frequency, and means for connecting the cathode and one grid across the inductance element and for connecting the cathode and other grid across the series tuned path.

2. A detector circuit comprising an inductance element and a capacity element connected in a series tuned path and an electron discharge device having a cathode, two grids and an anode, one of the series tuned path elements being connected between one grid and the cathode, and

the entire series path being connected between the other grid and the cathode.

3. A frequency selective apparatus comprising two paths connected in series, one path having a reactance of positive sign at a predetermined frequency, the other path having a reactance of negative sign at the same predetermined frequency, an electron discharge device having a cathode connected to the free end of one of the paths, an anode, a space current source connected to the cathode and anode, an impedance control element connected to the free end of the second path, and a frequency cut-off grid connected to the junction of the two paths.

4. In combination, a receiving circuit for electric waves, a path comprising two portions in series connected to the receiving circuit, one portion of the path having a definite reactance at a given frequency which is inductive at that frequency and at all lower frequencies, the second portion having an equal reactance at the given frequency which is capacitive at the given frequency and at all higher frequencies, an electron discharge device having a cathode, an anode and two impedance controlling grids, connections each including a polarizing source between the cathode and anode and the cathode and one grid, means connecting the cathode to one terminal of said path, means connecting one of the grids to the opposite terminal of said path, and means connecting the other grid to substantially the junction point between the two series portions of said path.

5. In combination, a receiving circuit for electric waves, a series tuned path comprising an inductance element and a capacity element connected to the receiving circuit, an electron discharge device having a cathode, an anode and two impedance controlling grids, connections each including a polarizing source between the cathode and anode and the cathode and one grid, means connecting the cathode to one terminal of the series tuned path, means connecting one of the grids to the opposite terminal of the series tuned path, and means connecting the other grid to substantially the junction point of the inductance element and the capacity element in the series tuned path.

6. In combination, a receiving circuit for electric waves, a tuned path connected thereto and comprising an inductance element and a capacity element arranged in series, two electron discharge devices each having a cathode, an anode and two impedance controlling grids, an external anode-cathode path including a polarizing source connecting the cathode of each device to its respective anode, means connecting the cathode of one device to one terminal of the tuned path and the cathode of the second device to the opposite terminal, means connecting one impedance control grid of each device to the terminal of the tuned path opposite the cathode connection of the same device, and means connecting the second impedance control element of each device to the junction point of the inductance element and capacity element in the tuned path.

7. An electron discharge device having a cathode and an anode, a source of space current connected between the cathode and anode, two impedance control elements interposed between said cathode and anode and input paths connecting each of said elements to said cathode, one of said

input paths including a source of biasing potential to prevent flow of space current in the absence of impressed oscillations, a circuit connected to both of said paths to impress oscillations thereon simultaneously, and one of said paths being tuned to a definite frequency whereby the reactance of the path changes sign as impressed oscillations pass through the definite frequency so that for oscillations of a frequency at one side of the definite frequency the impedance control elements are subjected to potentials of opposite phase and for oscillations of a frequency at the other side of the definite frequency the potentials to which the impedance control elements are subjected are in phase agreement.

8. In combination, an electron discharge device having a cathode, an anode and three grids, an input circuit tuned to a definite frequency connected between the cathode and one grid, means for connecting a second one of the grids to an intermediate point in the input circuit which is electrically sufficiently remote from both the cathode and the first grid so that relatively large alternating electromotive forces at the definite frequency are produced between the point and the cathode and the first grid respectively, an output circuit including a space current source connected between the cathode and anode, and means for directly connecting the third grid to a point in the space current source.

9. In combination, an electron discharge device having a cathode, an anode and an output circuit including a space current source connecting the cathode and anode, an impedance control grid within the device, a tuned input circuit connected to the cathode and impedance control grid, the connection to the impedance control grid including a resistance of high magnitude, a second impedance control element within the device connected to an intermediate point which is electrically sufficiently remote from both the cathode and the first impedance control grid so that relatively large alternating electromotive forces are engendered in the operation of the circuit between the point and the cathode and the first impedance control grid respectively in the input circuit, and a space charge grid also within the device and connected directly to a point in the space current source.

10. In combination, an electron discharge device having an effective source of electrons, an anode, an impedance control element associated with the device, an input circuit tuned to a definite frequency connected between the source of electrons and the impedance control element, a second impedance control element associated with the device, means for connecting the second impedance control element to a point in the circuit connecting the first impedance control element and the electron source which is electrically sufficiently remote from both the first impedance control element and the source so that in operation a relatively large alternating electromotive force is set up between the point and the first control element and a relatively large alternating electromotive force is set up between the point and the source, an output circuit including a space current source connected between the source of electrons and the anode, and means in the output circuit for transferring alternating current energy to a work circuit.

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